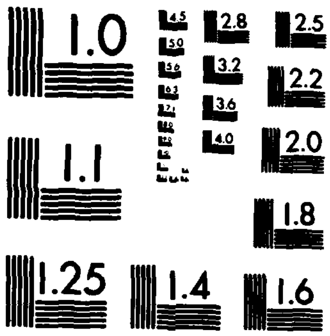
AD-A152 865 STUDIES OF OPTICAL-BEAM PHASE-CONJUGATION BY NONLINEAR REFRACTION(U) UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES ELECTRONIC SCIE.. R W HELLWARTH 31 DEC 84 1/1

UNCLASSIFIED AFOSR-TR-85-0283 F49620-83-C-0045 F/G 20/6 NL

END
FILMED



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR- 85-0283	2. GOVT ACCESSION NO. ---	3. RECIPIENT'S CATALOG NUMBER ---
4. TITLE (and Subtitle) Studies of Optical-beam Phase-conjugation by Nonlinear Refraction		5. TYPE OF REPORT & PERIOD COVERED 12/3/82 - 12/2/83 Annual Scientific
		6. PERFORMING ORG. REPORT NUMBER ---
7. AUTHOR(s) Robert W. Hellwarth		8. CONTRACT OR GRANT NUMBER(s) F49620-83-C-0045
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Southern California Los Angeles, CA 90089-0484		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2301/A1
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research Bolling Air Force Base Washington, D.C. 20332		12. REPORT DATE 12/31/84
		13. NUMBER OF PAGES 10 plus documentation page
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) ----		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

DTIC ELECTE APR 25 1985 S D B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Air Force position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

coherent Raman spectroscopy, photorefraction, optical resonators, sodium vapor, nonlinear spectroscopy, resonance light scattering, phase conjugation, fourwave mixing, nonlinear optics, liquid crystals, fiber optic gyroscopes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Studies of optical beam phase conjugation by a variety of physical processes and their application to spectroscopy, gyroscopy, and optical information processing continued.

DD FORM 1 JAN 73 1473

unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

1. Introduction and Objectives

Nonlinear optics, the study of matter interactions with intense electromagnetic fields, has uncovered surprising and useful physical effects, such as stimulated scattering of light by which an intense monochromatic beam can be converted to intense coherent beams of different wavelengths. Recently interesting processes involving nonlinear optical image-bearing beams have been discovered, such as optical-beam phase conjugation. Optical beam phase conjugation is the name given any process which generates, in real time, the time-reversed replica of a complex, image-bearing, optical beam, or which generates other related reflected beams, both monochromatic and polychromatic. Device applications of phase-conjugation include correction of image aberrations, rightness enhancement of laser outputs, and automatic steering of beams, at optical and other wavelengths. Also, such nonlinear optical techniques are being extended to perform many forms of beam processing, sorting, and routing on pico second time scales. This project aims at exploring and developing these and other new wave-mixing processes, and the necessary nonlinear materials. Other novel electromagnetic scattering processes which occur at the intense optical fields available from lasers are also explored for their scientific and device interest. The approaches taken in this project are both experimental and theoretical.

2. Major Accomplishments of Current Grant Period - (12/3/82-12/2/83.)

The major accomplishments of the current grant period were: (1) the first theoretical study of pump beam requirements for phase conjugation by a general scattering process: results promise low power requirements at infrared and longer wavelengths, (2) the establishment of a more accurate value for the standard scattering cross-section of the 992 cm^{-1} Raman line of benzene and its wavelength dependence. Also, we made the first determination of wavelength dispersion of the nonlinear refractive index of benzene, which gives the best available standard for comparative measurements,

(3) the first quantitative measurements of the effect of applied static electric fields on the buildup and decay of photorefractive gratings, (4) a study of the energy requirements for optical logic using photorefraction, and (5) the first unambiguous measurements of the three parameters needed to predict all photorefractive effects in bismuth silicon oxide for changes slower than an electron recombination time.

2.1. Low power cw phase conjugation.

We have demonstrated theoretically that phase conjugation with reflectivity near unity can be achieved by cw degenerate four-wave mixing in any medium in which beam attenuation arises mainly from scattering with pump beam intensities or order

$$I_o = n^2 k_B T \omega^3 / c^2, \tag{1}$$

where n is the refractive index, k_B is Boltzmann's constant, T is the absolute temperature, ω is the angular frequency of its beams, and c is the velocity of light. This means pump intensities of only 10^{-4} W/cm^2 will be required for ten micron radiation, or only $\sim 10^{-13}$ W/cm^2 should be required for one centimeter radiation.

2.2. Establishment of nonlinear index, dispersion, and light scattering standards.

We have completed experimental spectral studies of the 992 cm^{-1} Raman quintuplet in benzene using Raman-induced phase conjugation (RIPC). These give an accurate ($\pm$10%) value of the ratio of Raman to Rayleigh intensities from which we obtain the most accurate values to date for this benzene Raman cross-section (the most used standard) and its variation with wavelengths from the infrared to 360 nm. We were also able to determine the wavelength dependence of the nonlinear refractive index of benzene, making it the first such standard for the dispersion of self-focusing thresholds and of the "B integral".

2.3. Effect of applied electric field on the buildup and decay of photorefractive gratings.

Using a model of simple drift and diffusion for electron transport in the conduction band, Kukhtarev has predicted that, in the more sensitive photorefractive materials, a small applied electric field $E_o(>V/\ell)$ will produce a) dramatic slowing-down of the writing and erasing of photorefractive charge gratings, and b) large temporal oscillations during writing. (Sov. Tech. Phys. Lett. 2, 433, (1976).) (Here V=Boltzmann's constant times temperature divided by the electron charge; ℓ=the grating period $\div 2\pi$.) This is predicted if ℓ is less than the average distance d moved by an optically excited electron (with E_o=0) before recombination, but is greater than the Debye screening length. We have made the first quantitative experimental check of this slowing down, writing a grating of $\ell \sim 0.5$ microns with intersecting 488 nm laser beams in a nominally-undoped crystal $Bi_{12}SiO_{20}$. The above conditions are satisfied. The grating amplitude is monitored by Bragg diffraction of a weak 633 nm laser beam. The internal value of E_o produced by different applied voltages is determined by the electro-optic effect experienced by the 633 nm beam. We have verified the quantitative predictions of Kukhtarev for the rise and decay functions for 488 nm intensities up to 0.1 W/cm_2 and E_o up to 8 kV/cm, observing field-induced-slowing off up to 25 times.

These experiments were made possible by collaboration with G. Roosen of the Institut d-Optique (Orsay, France) who supplied the electrode technology necessary to create stable, constant, and calibrated internal electric fields.

2.4. Energy requirements for optical logic using photorefraction.

We have continued theoretical studies of the lower limit on the optical energy required to perform one logic operation by four-wave-mixing in photorefractive materials. For materials of high quantum efficiency and sufficient electro-optic coefficient (such as possessed by barium titanate), this lower limit was found to be of order $10^3 n \epsilon k_B\ Tm^2$, where ε is the dc dielectric constant and m is the number of wavelengths of interaction required to obtain unity scattering efficiency from a photorefractive grating of period half-optical wavelength. ($m \sim 10^2$ for barium titanate). This indicates for example a practical limit of picojoules per operation for optimally doped barium titanate.

2.5. Optical measurement of the photorefractive parameters of bismuth silicate.

We have completed measurements of all three photorefractive parameters of bismuth silicate necessary to predict all optical interactions, with or without applied electric fields, in the "adiabatic" regime where all process times are along compared to the electron recombination time (~microseconds). These parameters are a) an effective density of active electron trap sites (which we find to be 1.4×10^{16} cm^{-3} for 515 nm beams), b) an average hopping distance or range travelled by an electron in a single excitation-recombination process (which we find to be ~3 microns), and c) the rate of electron excitation per unit light intensity per unit volume (which we find contributes ~1.4 cm^{-1} to beam attenuation at 515 nm). This latter measurement with the measured absorption coefficient indicates near unity quantum efficiency. Our measurements were performed using only optical techniques, thus avoiding electrical contact problems inherent in previous methods, which are much more difficult to interpret in any case. Our method was to measure the dependence on writing beam angles and erasure intensities of the decay times of photorefractive holograms.

3. Published Papers From This Project

3.1. "Theory of phase-conjugation in waveguides by four-wave mixing," R.W. Hellwarth, IEEE Journ. Quant. Elect. QE15, 101 Feb. 1979.

3.2. "Generation of time-reversed waves by nonlinear refraction in a waveguide," S.M. Jensen and R.W. Hellwarth, Appl. Phys. Lett. 33, 404, Sept. 1978.

3.3. "Infrared-to-optical image conversion by Bragg reflection from thermally-induced index gratings," G. Martin and R.W. Hellwarth, Appl. Phys. Lett. 34, 371 (1979).

3.4. "Spatial-diffusion measurements in impurity-doped solids by degenerate four-wave mixing," D.S. Hamilton, D. Heiman, Jack Feinberg, and R.W. Hellwarth, Optics Letters 4, 124 (1979).

3.5. "Generation of time-reversed replicas of optical beams in barium titanate," Jack Feinberg, D. Heiman, and R.W. Hellwarth, Bulletin of the 1978 Annual Meeting of the Opt. Soc. of Am., 1367, Oct. 1978.

3.6. "Raman-induced Kerr Effect - A new laser-plasma diagnostic," M.V. Goldman and R.W. Hellwarth, Bull. Am. Phys. Soc. 23, 893, Sept. 1978.

3.7. "Conjecture on the effect of small anharmonicity on vibrational modes of glass," R.W. Hellwarth, Sol. State Comm. 32, pp. 85-88 (1979).

3.8. "Photorefractive effects and light-induced charge migration in barium titanate", Jack Feinberg, D. Heiman, R.W. Hellwarth, and A. Tanguay, J. Appl. Phys. 51, pp. 1397-1305, March, 1980.

3.9. "Generation of a time-reversed replica of a nonuniformly polarized image-bearing optical beam", G. Martin, L.K. Lam, and R.W. Hellwarth, Optics Lett. vol. 5, pp. 185-187, May, 1980.

3.10. "Real-time edge enhancement using the photorefractive effect", Jack Feinberg, Optics Letters, vol. 5, pp. 330-332, Aug. 1980.

3.11. "Four-wave mixing in photorefractive materials", Jack Feinberg and R.W. Hellwarth, Paper and Abstract E.3, Proceedings of XI International Conference on Quant. Elec., Boston, June 23-26, 1980.

3.12. "A wide-angle narrowband optical filter using phase-conjugation by four-wave mixing in a waveguide", L.K. Lam and R.W. Hellwarth, Abstract E.10, Proc. XI Intl. Quant. Elect. Conference, Boston, June 23-26, 1980.

3.13. "High resolution resonance Raman spectroscopy of Iodine Vapor", D. Kirillov, and R.W. Hellwarth, Bull. Am. Phys. Soc., vol. 25, No. 9, p. 1129, Nov. 1980.

3.14. "Pulsed phase conjugation due to a tensor refractive index grating in sodium vapor", S.N. Jabr, L.K. Lam and R.W. Hellwarth, Bull. Am. Phys. Soc., vol. 25, No. 9, p. 1124, Nov., 1980.

3.15. "Phase-conjugation with nanosecond laser pulses in $BaTiO_3$", L.K. Lam, T.Y. Chang, Jack Feinberg and R.W. Hellwarth, Abstract, Bull.

Optical Soc., Fall 1980 meeting, Chicago.

3.16. "Phase-conjugating mirror with continuous-wave gain", Jack Feinberg and R.W. Hellwarth, Optics Letters, 5, pp. 519-521, Dec., 1980.

3.17. "New component in degenerate four-wave mixing of optical pulses in sodium vapor", S.N. Jabr, L.K. Lam and R.W. Hellwarth, Phys. Rev. A., vol. 24, pp. 3264-3267, Dec., 1981.

3.18. "High resolution resonance Raman spectroscopy in the B-X band of $^{127}I_2$ vapor", D. Kirillov, L.K. Lam and R.W. Hellwarth, J. Molec. Spectroscopy, vol. 91, pp. 269-272, Jan., 1982.

3.19. "Photorefractive index gratings formed by nanosecond optical pulses in $BaTiO_3$", L.K. Lam, T.Y. Chang, Jack Feinberg and R.W. Hellwarth, Optics Lett., vol. 6, pp. 475-477, Oct., 1981.

3.20. "Asymmetric self-defocusing of an optical beam from the photorefractive effect", Jack Feinberg, J. Opt. Soc. Am., 72, pp. 46-51, Jan., 1982.

3.21. "Optical beam phase conjugation by stimulated backscattering", R.W. Hellwarth, Optical Engineering, vol. 21, pp. 263-266, Mar/Apr, 1982.

3.22. "Optical beam phase conjugation by four-wave mixing in a waveguide", R.W. Hellwarth, Optical Engineering, vol. 21, pp. 263-266, Mar/Apr, 1982.

3.23. "Observation of intensity-induced nonreciprocity in a fiberoptic gyroscope", S. Ezekiel, J.L. Davis, and R.W. Hellwarth, Proc. of International Conference on Fiberoptic Rotation Sensors (M.I.T., (Nov. 9-11, 1981)) ed. by S. Ezekiel (Springer-Verlag, New York, 1982).

3.24. "Observation of intensity-induced nonreciprocity in a fiber optic gyroscope", S. Ezekiel, J.L. Davis, and R.W. Hellwarth, Optics Lett. vol. 7, pp. 457-459, Sept. 1982.

3.25. "Optical beam phase conjugation by stimulated backscattering in multimode optical waveguides", R.W. Hellwarth, in New Directions in Guided Waves and Coherent Optics, vol. II, pp. 335-357, ed. by D.B. Ostrowsky and E. Spitz (Martinus Nijhoff Pub., Boston, 1984).

3.26. "Raman-induced phase conjugation spectroscopy", S.K. Saha and R.W. Hellwarth, Phys. Rev. A, vol. 27, pp. 919-922, Feb., 1983.

3.27. "Phase conjugation by stimulated backscattering", R.W. Hellwarth, Chapter 7 of Optical Phase Conjugation, ed. by R.A. Fisher (Academic Press, New York, 1983).

3.28. "Phase conjugation by four-wave-mixing in a waveguide", R.W. Hellwarth, Chapter 5 of Optical Phase Conjugation, ed. by R.A. Fisher (Academic Press, New York, 1983).

3.29. "Holographic time-resolved measurements of bulk space-charge gratings in photorefractive bismuth silicon oxide", R.A. Mullen. Thesis presented for Ph.D. in Electrical Engineering, 7 December 1983.

4. Talks from this project in current reporting period (6/83 to 6/84).

4.1. "The photorefractive effect for phase conjugation", R.W. Hellwarth, Optics Group Seminar, Royal Signals and Radar Establishment, Gt. Malvern (England), June 21, 1983.

4.2. "Stimulated Brillouin scattering - a collective mode", R.W. Hellwarth, Many-body Seminar, Universite Libre de Bruxelles, Brussels (Belgium), 1 July 1983.

4.3. "Optical beam phase conjugation - a review", R.W. Hellwarth, Physics Seminar, University of Paris VI, 15 July 1983.

4.4. "Sound damping and non-propagating index fluctuations in optical glasses", R.W. Hellwarth, Solid State Seminar, Clarendon Laboratory, Oxford, 24 July 1983.

4.5. "Optical beam phase conjugation - a review", Physics Department, University of New Mexico, Albuquerque, New Mexico, 11 Nov. 1983.

4.6. "Non-reciprocal phase shifts from the photorefractive effect", R.W. Hellwarth, Conference on Physics of Optical Ring Gyros, Snowbird, Utah, 8 Jan. 1984.

4.7. "Error in phase conjugation by stimulated Brillouin scattering", R.W. Hellwarth, 14th Winter Colloquium on Quantum Electronics, Snowbird, Utah, 12 Jan. 1984.

4.8. "Optical beam phase conjugation - a review", R.W. Hellwarth, Institut d'Optique, Orsay, France, 19 April 1984.

4.9. "Stimulated Brillouin and Raman Scattering", R.W. Hellwarth, Hughes Aircraft Co., Electro-Optical and Data Systems Group Seminar, 9 Dec. 1983.

4.10. "Phase-conjugation for physical measurement", R.W. Hellwarth, Ecole Normale Superieur, Paris, France, 24 May 1984.

4.11. "The photorefractive effect", R.W. Hellwarth, U. of Paris Nord, Paris, France, 15 May 1984.

4.12. "Use of phase conjugation for physical measurement", R.W. Hellwarth, Invited paper ThAA1, XIII International Conference on Quantum Electronics, Anaheim, Calif., 21 June 1984.

END

FILMED

5-85

DTIC